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GROWTH MODELING AND SPATIO-TEMPORAL VARIABILITY IN THE BODY CONDITION OF THE ESTUARINE SHRIMP *PALAEMON LONGIROSTRIS* IN THE GIRONDE (SW FRANCE)

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A B S T R A C T

Growth and morphometric characteristics of the caridean *Palaemon longirostris* Milne Edwards, 1837, were studied in the Gironde estuary population. Their first comparison with earlier studies in this estuary and in the Mira River provided the first step towards developing environmental indicators using a species represented at the European scale. Mean individual growth was modelled for each sex using the classical von Bertalanffy growth model and the seasonal model that integrates periods of lower growth. Morphometric relationships, in particular the spatio-temporal variability in the relative weight of individuals, were explored according to sex and physical parameters of the environment. Females grew to larger size than males. Growth estimates showed the importance of accounting for the seasonal variations to evaluate non-biased growth. Sex and the presence of eggs for females showed significant interaction within the carapace length – total length relation as well as for the carapace length – weight relation. Body condition was significantly greater in spring and summer for both sexes and was significantly correlated with salinity, but only for males. Comparison with the Mira River was limited to the range of data available. However, the population of the Gironde estuary, being similar in both recent and historical studies, showed morphometric differences when compared to that of the Mira River. Indeed, the growth performance index was higher in the Gironde estuary and likely linked to temperature constraints. Conversely, differences between males and females were much higher in the Mira River than in the Gironde estuary.

KEY WORDS: environmental indicator, estuary, growth performance, *Palaemon longirostris*, seasonal VBG

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INTRODUCTION

For many marine species, estuaries and coastal areas serve as essential habitats and are thus characterized by high levels of fisheries production (Costanza et al., 1997). Conserving these areas represents a major challenge in ensuring the viability of both resident and transient populations that live there. These ecosystems are being negatively affected by increased human activity, particularly pollution (Halpern et al., 2008). Such man made pressures acting within the broader context of global warming result in the fundamental need to develop environmental quality indicators to better manage these ecosystems (Deegan et al., 1997; EU, 2000). However, the use of a species as an environmental indicator requires a good knowledge of its biological attributes and their relation with physical parameters. Furthermore, this also requires observations and comparisons at different temporal and spatial scales.

In this respect, estuarine shrimps present many advantages. As estuarine residents, they are present year round (Gurney, 1923; Campbell and Jones, 1989; González-Ortegón et al., 2006), are able to record the prevailing conditions, and are generally numerous and easy to sample. The present study focused on the shrimp *Palaemon longirostris* Milne Edwards, 1837 given that it was recorded in several estuaries: 1) along the Atlantic coast

of Europe (d' Udekem d'Acoz, 1999): in UK (Gurney, 1923; Smaldon et al., 1993), in Holland (De Man, 1923; van den Brink and van der Velde, 1986), in French West Channel (Bourdon, 1965; Marchand, 1981), in the Gulf of Biscay (De Man, 1923; Auroousseau, 1984), in Portugal (Neves, 1970; Cartaxana, 1994); in Spain (González-Ortegón and Cuesta, 2006) and Morocco (Elkaim, 1974); 2) in the Black Sea (Sezgin et al., 2007); and 3) probably in the Mediterranean (d' Udekem d'Acoz, 1999).

In the Gironde estuary, *P. longirostris* is the most common and abundant shrimp and is a key species in the estuarine trophic network (Lobry et al., 2008). Targeted by commercial fishing fleets, it represents about 11% in weight (30.8 t in 2009) and 7% in value (523.7 k € in 2009) of the Gironde fishery landings (Girardin et al., 2008). Furthermore, *P. longirostris* is also an important prey item for many other target estuarine species, such as bass, *Dicentrarchus* sp., and the meagre, *Argyrosomus regius* (Pasquaud et al., 2008).

Since growth may be a good index for environmental conditions, including the seasonal fluctuations of growth for a shrimp species is a prerequisite for modelling population dynamics under different natural and anthropogenic constraints. The present study aimed at describing and modelling the different characteristics of growth and size of *P. longirostris* in the Gironde estuary. This

description completed previous papers from Portuguese studies while accounting for early stages and seasonality. Morphometric characteristics were then studied according to sex, season and physical parameters. Results of previous works in the Gironde estuary (Aurousseau, 1984) and in the Mira estuary were compared all along the results.

MATERIALS AND METHODS

Sampling

From November 2006 to November 2007, bottom trawl surveys were carried out each month throughout the Gironde estuary (Fig. 1). These surveys targeted both the bottom using an Agassiz trawl (2.0×1.2 m, mesh size = 1.0 mm), and surface waters using two rectangular frame push-nets (4.0×1.0 m, mesh size = 1.0 mm). Surveys were systematically performed during daytime, at the halfway stage between flood tide and high tide slack. The collected samples were stored in plastic containers and conserved in 70% ethanol. At each station, temperature ($^{\circ}\text{C}$), salinity (PSU) and turbidity (NTU) were stored using a multi-parameter probe IDROMAR IM51-IM201.

For each sample, different biological parameters for all individuals (or a representative sample) were recorded. Males were identified by the presence of an appendix masculina on the second pair of pleopods and ovigerous females were differentiated from non-ovigerous ones. Lengths were measured under a binocular microscope to the nearest tenth of a millimeter. The carapace length (CL) was measured from the orbital edge of the eye to the edge of the cephalothorax (Brêthes and O Boyle, 1990; Cartaxana, 2003) and the total length (TL) was measured from the edge of the eye to the end of the telson. Individuals were weighed to the nearest milligram after a few days of storage in alcohol. The dehydration caused by immersion in alcohol was estimated by a preliminary experiment. The following linear relationship between the wet weight before alcohol (W_w) and few weeks after (W_{wa}) was obtained: $W_w = (1.1790 \times W_{wa}) - 0.0227$.

Cohort Analysis and Growth Modelling

Size frequency of individuals showed two cohorts for each sex for some sampling months. A polymodal decomposition model was thus used to assign an age to each individual of the samples with the modal progression method, commonly used for crustaceans (Bergstrom, 1992; Cartaxana, 2003). Individual length was split into 1 mm-length classes. Cohorts, with respect to sex and sampling month, were differentiated using the Mixdist package (Macdonald and Green, 1998) supported by R (R Foundation Core Team, 2005), which allowed the polymodal decomposition of the observed size frequency histograms that assumed a Gaussian distribution (Cartaxana, 2003). Size distribution of individuals of indeterminate sex (juveniles) suggested no difference between future males and females.

The polymodal decomposition model allowed assigning each individual to a specific cohort. A growth curve was then adjusted for all individuals. Traditionally, growth is fitted using a von Bertalanffy model –VBG– (von Bertalanffy, 1938; Garcia and Le Reste, 1981):

$$L(t) = L_{\infty}(1 - \exp(-K(t - t_0))) \quad (1)$$

where t is the age of the cohort (in year from 1st June), $L(t)$ is the size at age t (in mm), L_{∞} is the asymptotic length (in mm). K (in year^{-1}) is the growth constant or curve parameter. t_0 (in year) is the age at $L(t_0) = 0$.

Growth of crustaceans is characterized by a series of plateaus that mirrors the cycle of successive seasons (van den Brink and van der Velde, 1986). The traditional VBG equation (Eq. 1) does not account for these seasonal variations in growth. Nevertheless, different models incorporating seasonal variations and periods of zero growth, do exist (e.g., Hoenig and Hanumara, 1982; Bilgin et al., 2009). One such model, developed by Pauly et al. (1992) stays close to the original VBG equation and provides ecologically interpretable parameters:

$$L(t) = L_{\infty}(1 - e^{-q}) \quad (2)$$

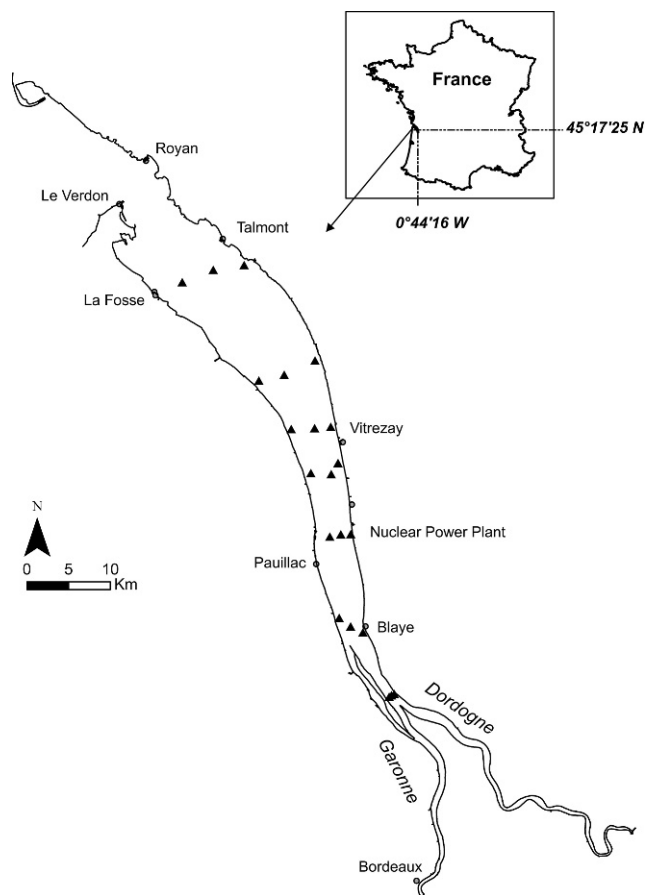


Fig. 1. The Gironde estuary. Triangles: sampling stations repeated monthly between November 2006 and November 2007.

$$q = K'(t' - t_0) + K'/Q[\sin Q.(t' - t_s) - \sin Q.(t_0 - t_s)] \quad (3)$$

$$Q = 2\pi/(1 - \text{NGT}) \quad (4)$$

where K' (year^{-1}) is the growth parameter, t' (year) is the length of the periods of higher growth, t_s (year) is the date of starting higher growth; NGT (year) is the no-growth time before the first period of growth. L_t , L_{∞} , t_0 are similar to those used in Equation 1.

The number of parameters used was important in the seasonal VBG model. Contrary to fits within the classical VBG, the asymptotic length (L_{∞}) of the seasonal VBG was fixed. This was calculated using the carapace length of the largest collected specimen (L_{max}) and the relationship obtained by Taylor (1962): $L_{\infty} = L_{\text{max}}/0.95$.

Estimates of the Mira River (Cartaxana, 2003) and of historical data (Aurousseau, 1984) were fitted according to the classical VBG model. To allow for qualitative comparisons, the classical VBG was thus fitted to corresponding subsets of our data. The classical growth performance indices (Φ , Eq. 5; Pauly and Munro, 1984), obtained from the fits with the classical VBG were also compared:

$$\Phi = 2 \log_{10} L_{\infty} + \log_{10} K \quad (5)$$

Analysis of Biometric Relationships

Relationships between TL and CL and between W_{wa} and CL were examined using generalized linear models (GLM). A stepwise parsimonious approach allowed for the testing of differences in morphometric parameters between sexes through the Akaike criterion (AIC). While considering two models: 1) $TL \sim a[\text{sex}] * CL + b[\text{sex}]$ (non-allometric within the range of data), and 2) $\log(W_{wa}) \sim a[\text{sex}] * CL + b[\text{sex}]$

Table 1. Size frequencies of *Palaemon longirostris* sampled in the Gironde estuary between November 2006 and November 2007, issued from the polymodal decomposition. M: maximum likelihood carapace length (CL), Sd: CL standard deviation, P: proportion of individuals in the month sample and N: amount of individuals observed. Recruits (Age 0) are separated from individuals older than 1-year old (1+).

Date	Females				Males					
	N	Cohort 2007 (Age 0)		Cohort 2006 (1+)		N	Cohort 2007 (Age 0)		Cohort 2006 (1+)	
		M (± SD)	P	M (± SD)	P		M (± SD)	P	M (± SD)	P
14/11/2006	253			9.2 (± 1.5)	1.00	485			7.3 (± 0.8)	1.00
13/12/2006	146			9.4 (± 2.0)	1.00	245			7.9 (± 1.1)	1.00
16/01/2007	99			10.1 (± 1.8)	1.00	201			7.8 (± 0.8)	1.00
12/02/2007	184			9.7 (± 1.5)	1.00	231			7.7 (± 0.8)	1.00
15/03/2007	140			9.9 (± 1.5)	1.00	188			7.8 (± 0.7)	1.00
12/04/2007	171			9.4 (± 1.6)	1.00	181			7.9 (± 0.8)	1.00
30/05/2007	218			10.2 (± 1.2)	1.00	147			8.2 (± 0.7)	1.00
12/06/2007	309			10.0 (± 1.0)	1.00	302			8.2 (± 0.7)	1.00
10/07/2007	176	4.8 (± 1.7)	0.67	11.0 (± 1.2)	0.33	276	4.3 (± 0.9)	0.33	8.7 (± 0.7)	0.27
07/08/2007	122	7.5 (± 1.0)	0.78	11.6 (± 0.9)	0.22	179	6.6 (± 0.9)	0.83	9.2 (± 0.5)	1.00
06/09/2007	131	8.3 (± 1.8)	0.97	13.3 (± 0.1)	0.03	236	7.1 (± 1.3)	1.00		
09/10/2007	91	8.4 (± 1.7)	0.95	13.5 (± 0.2)	0.05	294	7.2 (± 1.1)	1.00		
14/11/2007	99	8.9 (± 1.8)	0.60			291	7.3 (± 1.1)	1.00		

(allometric within the range of data), the relevance of fitting a different a and b for different sexes was tested. The more parsimonious models, i.e., the highest variance explained with the lowest amount of parameters, were retained according to both the significant lowest AIC (difference of 5 was retained as a minimum) and the significance of sex and/or presence of eggs in the analysis of variance (Fisher's test) of the model. Sex categories were male, non-ovigerous females and ovigerous females.

In order to explore the spatio-temporal variations of body condition, the relative weights of individuals (W_r) were calculated. Indeed, the body condition may be a good indicator of environmental conditions: the bigger the individuals of a given length, the better the conditions of growth and survival (Blackwell et al., 2000). Relative weight for each individual was defined as the ratio of the observed weight on the fitted weight calculated from the adjusted morphometric equation detailed above: $W_r = f(CL)$. The calculation of relative weights was a mean of simplifying the analysis of the residuals of this log-scaled equation ultimately allowing for the evaluation of the effects of physical parameters on the size and weight of individuals. Effects of season, salinity, turbidity and density-dependence were tested in GLM for different sex categories, except for non-ovigerous females, only caught during a short insufficiently contrasted period. As before, AIC permitted the choosing of the more parsimonious model combining these parameters and their interactions if significant. Salinity and turbidity were tested as continuous variables. Density-dependence was included as monthly mean densities grouped into 4 classes (< 25 ; [25-75]; [75-150]; $> 150 \times 10^{-3} \text{ m}^{-3}$ individuals). This represented a compromise between size of classes and a balanced partitioning of individuals among classes.

RESULTS

Monitoring Cohorts and Estimating Growth Curves

During the first eight months of sampling, a single cohort was noticeable for each sex (Table 1). The average size of the males was 7.8 mm CL and 9.7 mm CL for females. A second cohort appeared from July 2007, with an average size of 4.8 mm CL for males and 4.3 mm CL for females, corresponding to the recruitment of that year.

The growth between males and females was estimated from the seasonal VBG equations (Fig. 2a). This model reproduced well the successive seasonal variations for both sexes for which parameters were reported in Table 2. Figure 2b highlighted the bias induced while not including the seasonality in the VBG model. Indeed, for both sexes in our study, estimates of size for the oldest individuals were greatly underestimated.

Within the range of data observed, a slight difference appeared with the shrimps of the Mira River (Fig. 2b). Males were bigger in the Gironde estuary, whereas females were smaller depending on the VBG model compared. Growth performance for males and females of the Mira river (Φ males = 1.93, Φ females = 2.13) were lower than for these of the Gironde population (Table 2). Depending on the model compared, historical estimates showed slight differences for the growth of females but the fit was within the same range. Males seemed to be bigger in the recent period. However, growth performance indices of historical data (Φ males = 1.36, Φ females = 1.63) were lower than in the recent period (Table 2).

Morphometric Relationships

Shrimps sampled from the population of *P. longirostris* in the Gironde estuary had a CL measuring between 2.6 and 14.6 mm, and weighed between 0.029 and 1.932 g with differences between sexes. On average, females (non-ovigerous: 7.9 ± 2.0 mm; ovigerous 9.8 ± 1.4 mm) were bigger than males (6.9 ± 1.2 mm) of the same age. Females (non-ovigerous: 0.425 ± 0.278 g; ovigerous 0.751 ± 0.279 g) were also heavier than males (0.290 ± 0.126 g).

For the TL-CL relationship, the more parsimonious model showed that separating males and females was not necessary, except for ovigerous females, for which the slope of the relation was significantly lower for a same CL ($P < 0.05$; Fig. 3a). Estimates of parameters for the TL-CL relationship were thus common for males and non-ovigerous females ($TL = 9.7870 + 2.3689CL$, $r^2 = 0.72$, $N = 980$, $P < 0.001$) and different for ovigerous females ($TL = 8.03551 + 2.6314CL$, $r^2 = 0.85$, $N = 223$, $P < 0.001$).

Graphical comparison with Cartaxana (2003) show that French female shrimps are bigger for the same carapace length (Fig. 3b). However, the relationship was different for males, with an intersection around 10 mm, which was the upper limit of observations in our dataset (Fig. 3b). Comparison with historical data (Aurousseau, 1984) showed the population of 1982-83 was bigger for the same carapace length (Fig. 3b).

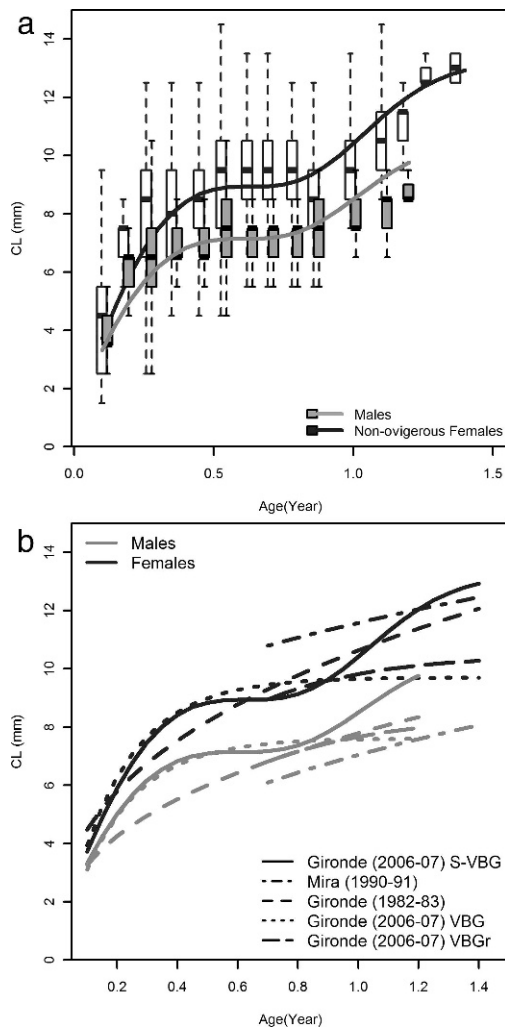


Fig. 2. Growth of *P. longirostris*. a – upper image) collected in the Gironde estuary in 2007. Data (box plots of carapace length [CL]) and fits (lines) of the seasonal VBG; b – lower image) comparison between adjustments on the present and on previous studies. S-VBG: Seasonal von Bertalanffy Growth equation (VBG); VBG: Classical VBG; VBGr: Classical VBG restricted to the same range of data as Cartaxana (2003). Mira population (Cartaxana, 2003): $CL_{\text{males}} = 11.68(1 - e^{-0.62(t + 0.49)})$; $CL_{\text{females}} = 16.32(1 - e^{-0.51(t + 1.42)})$; Gironde 1982–1983 (Aurousseau, 1984): $CL_{\text{males}} = 7.790t^{0.376}$; $CL_{\text{females}} = 10.628t^{0.376}$.

Considering the Wwa-CL relationship, the Akaike criterion favoured separated sex categories with significantly different parameters on the log scale. This resulted in visibly similar allometric relationships on the normal scale (Fig. 4a). Nevertheless, within the range of observed data,

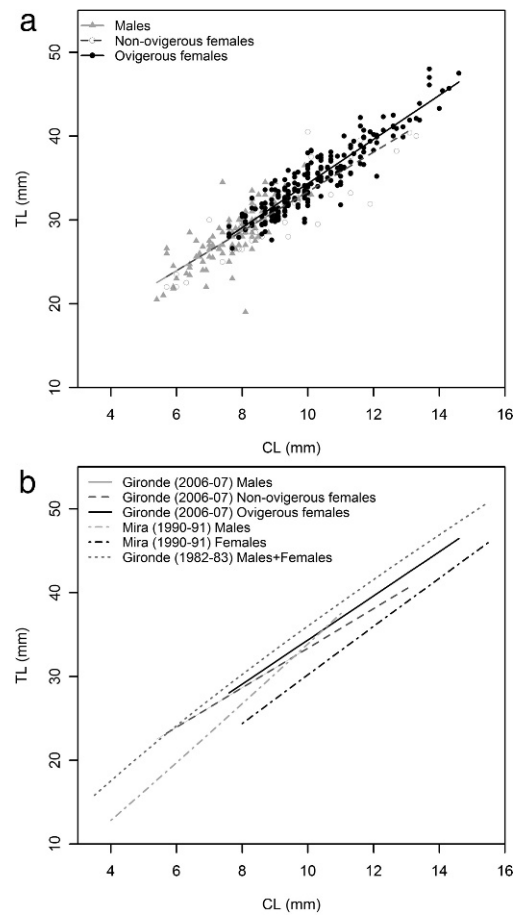


Fig. 3. Relationship between carapace length (CL) and total body length (TL). a – upper image) *Palaemon longirostris* male and female from Gironde estuary sampled between November 2006 and November 2007; b – lower image) comparison with historical data in the Gironde estuary (Males and females not distinguished; $TL = 5.9207CL^{0.7842}$, $r^2 = 0.97$, $N = 200$; Aurousseau, 1984) and Mira population ($TL_{\text{male}} = 2.95CL^{1.06}$, $r^2 = 0.97791$, $N = 911$; $TL_{\text{female}} = 3.31CL^{0.96}$, $r^2 = 0.98$, $N = 1229$; Cartaxana, 2003).

Wwa for a same CL was bigger for ovigerous females than for males ($Wwa_{\text{Males}} = 0.0017CL^{2.597}$, $r^2 = 0.88$, $N = 2055$, $P < 0.001$; $Wwa_{\text{ovigerous Females}} = 0.0014CL^{2.653}$, $r^2 = 0.81$, $N = 48$, $P < 0.001$), also being bigger than for non-ovigerous females ($Wwa_{\text{ovigerous Females}} = 0.0032CL^{2.368}$, $r^2 = 0.79$, $N = 506$, $P < 0.001$) (Fig. 4a).

Comparisons with other studies highlighted that non-ovigerous females from our dataset were the lightest individuals, whereas males from the Mira River were the

Table 2. Parameters of the classical and seasonal von Bertalanffy growth equations fitted for *P. longirostris* males and females sampled in the Gironde estuary between November 2006 and November 2007. K: growth constant. L_{∞} : asymptotic length, t_0 : age at $L(t_0) = 0$, NGT: no-growth time before the first period of growth, t_s : date of start of higher growth (Eq. 1–4). Φ : growth performance index (Eq. 5).

		K or K' (Year ⁻¹)	L_{∞} (mm)	t_0 (Year)	NGT	t_s (Year)	Φ
Females	Classical VBG	5.22	9.70	−0.01	—	—	2.69
	Classical VBG restricted	2.72	10.51	−0.06	—	—	2.48
	Seasonal VBG	1.05	15.33	−0.05	0.00	0.13	2.39
Males	Classical VBG	5.31	7.61	−0.06	—	—	2.48
	Classical VBG restricted	2.34	8.49	−0.12	—	—	2.23
	Seasonal VBG	1.09	12.17	−0.05	0.00	0.11	2.20

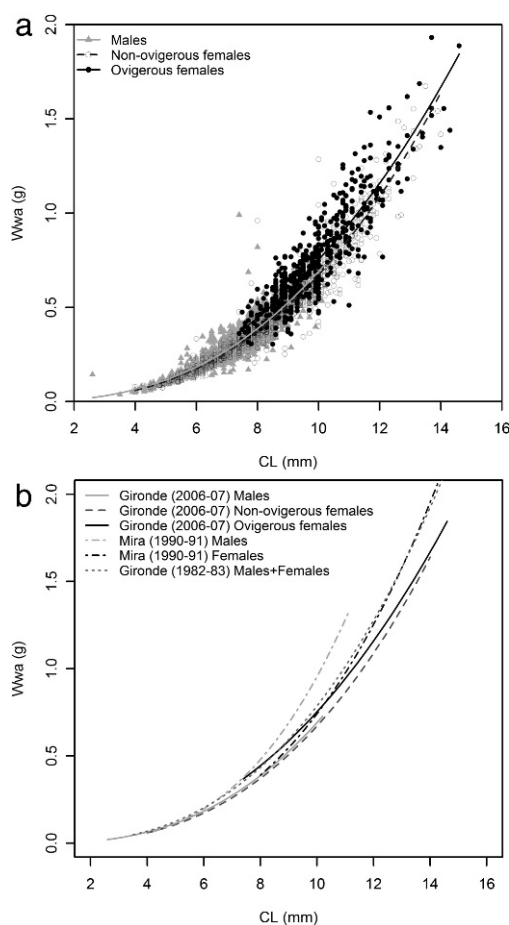


Fig. 4. Relationship between total body length (TL) and weight (Wwa). a – upper image) for *Palaemon longirostris* males and females of the Gironde estuary sampled between November 2006 and November 2007; b – lower image) comparison with historical data in this estuary ($W_{f\text{bothsexes}} = 0.00172CL^{2.6597}$, $r^2 = 0.99$, $n = 89$) and with the Mira population ($W_{f\text{males}} = 0.0007CL^{3.09}$, $r^2 = 0.97$, $N = 994$; $W_{f\text{females}} = 0.0009CL^{2.88}$, $r^2 = 0.98$, $N = 1232$).

heaviest for a same CL (Fig. 4b). Other relationships showed a similar pattern.

The analysis of body condition, using the AIC comparison of generalized linear models applied on the relative weights, enabled the demonstration of differences the effects of physical parameters between males and females. In particular, salinity brought about spatial differences in body condition for males, whereas no such differences were observed for females. Season affected body condition for both sexes, whereas neither densities nor turbidity had any effect. Consequently, the resulting models were:

$$\text{Log}(Wr[\text{females}]) \sim \text{Season} \quad (6)$$

$$\text{Log}(Wr[\text{males}]) \sim \text{Season} * \text{Salinity} + \text{Constant} \quad (7)$$

For females, only the season had an effect on Wr because body condition was lower in winter than for other seasons ($P < 0.001$, Fig. 5a). For males, the effect of season on the intercept of the relationship was not significant ($P = 0.2$). The effect of salinity was always positive (Fig. 5b.), except

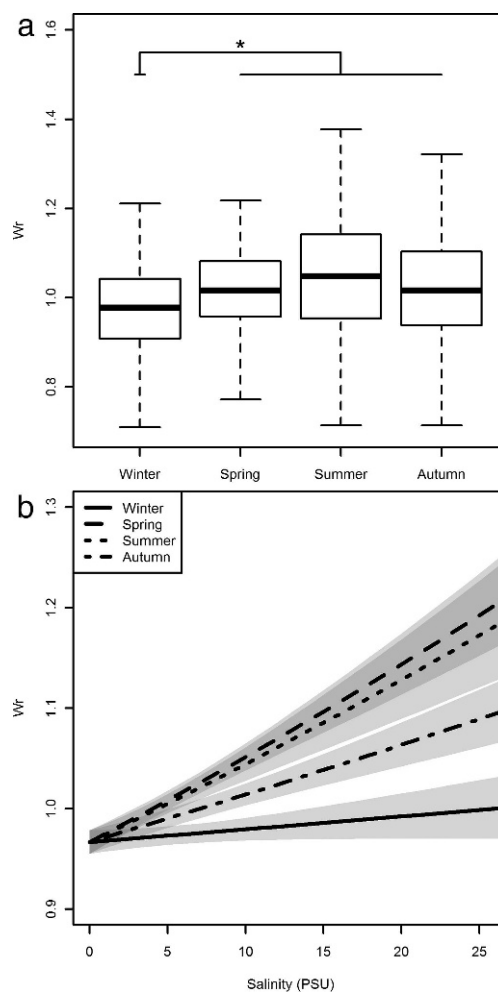


Fig. 5. Body condition (Relative weight, Wr) in relation to significant factors. a – upper image) raw Wr of *P. longirostris* females of the Gironde estuary between November 2006 and November 2007 related to season (*: $P < 0.05$; Eq. 6); b – lower image) adjusted Wr of males related to season and salinity (Eq. 7). The grey area represents the 95% uncertainty of the fit.

in winter where the slope was not significantly different from zero ($P = 0.07$). For a similar salinity, Wr was highest in spring and summer, autumn being intermediate.

DISCUSSION

Strength of the Approaches

The present paper offered new insights into the description of shrimp morphometric parameters to be used as environmental indicators. The characteristics of the life cycle of a shrimp such as *P. longirostris* and its occurrence across different ecosystems make it a particularly interesting species used to assess estuarine quality. However, its stepwise growth requires an appropriate modelling approach to evaluate coherent biological parameters that might represent indicators of environment quality. The growth modelling approach used in this paper shows the relevance of integrating early stage individuals (juveniles) in a seasonal model. Indeed, the comparison of the seasonal model with the classical VBG model applied on our dataset

showed the bias generated by not accounting for periods of lower growth. In another instance, the effects of physical parameters on the body condition of individuals provided information concerning the effects of the environment on shrimps. This contributed to highlight major factors that must be taken into account before comparing conditions among different areas and thus effect of water quality.

Growth Characteristics

This study enabled the assessment of seasonal mean individual growth models for the Gironde population of *P. longirostris* for each sex. This sort of seasonal differences in growth had already been observed in the Netherlands population (van den Brink and van der Velde, 1986). The periods of low growth correspond to the preparation for reproduction, since producing gametes requires energy reallocation (Hartnoll, 1985).

The modelling approach allowed for comparison with data of Cartaxana (2003) as well as historical data (Aurousseau, 1984). Indeed, the use of the growth performance index (Φ) is recommended over the intrinsic growth rates (K) for comparisons (Pauly and Munro, 1984). While compared under the same conditions, Φ were higher for the recent population in the Gironde than that in the Mira River. This observation may be linked to temperature as was observed for the marine shrimp *Crangon crangon* (Linnaeus, 1758) (cf. Campos et al., 2009). Shrimps living in the highest latitudes compensate for their shorter favourable growth period (with respect to temperature) by accelerating their growth during the short period of the year when temperatures are the highest. Comparison with historical data (Aurousseau, 1984) indicated better growth performance during recent times when compared to the early 1980s. Conversely, a comparison of growth adjustment for females showed similarities between both the historical and the recent study, whereas recently sampled males seemed to be bigger than historically sampled individuals.

However, the method and the comparisons faced different limitations. First, the low number of older females in our dataset biased the estimate of the classical VBG equation. This probably led to an underestimate in the size of older individuals. Also, the heavy commercial fishing pressure that targets the biggest individuals most likely acts to reduce their contribution to the sampling. Secondly, data from Cartaxana (2003) did not show any seasonal variation. The short period during which the sampling was carried out coupled with the long period of reproduction (January-August; Cartaxana, 1994) along the Mira River may have biased the estimated age of individuals sampled ultimately affecting the growth curve estimate. This issue should be considered further when making comparisons between areas. Lastly, the absence of long term sampling time series in the Gironde estuary prevented an estimation of interannual variability. Consequently, the comparison with historical data may not be considered as a long-term trend of the Gironde population.

Morphometric Characteristics

A specific characteristic of *P. longirostris*, also observed in several other species of *Palaemon* (Omori and Chida,

1988), is a pronounced sexual dimorphism with respect to size: females being larger than males in average. This sexual dimorphism was not marked for CL-TL relation when considering males and non-ovigerous females, which contradicts Anger and Moreira (1998) but is in accordance with Cartaxana (2003). However, the CL-Wwa relationships were different between sex categories. In both cases, comparisons with Cartaxana (2003) or Aurousseau (1984) showed slight differences. The presence of morphological anomalies in shrimps from our dataset (Béguer et al., 2008; Béguer et al., 2010b) may have had an influence on these indicators and this might also have been true of the high level of organic contamination in the Gironde estuary. However, disentangling these effects requires broader analyses with other areas, something that is not possible at the present time, notably because of the lack of equations provided by previous works (Marchand, 1981; van den Brink and van der Velde, 1986).

Variability in Body Condition of Individuals

Changes in seasons induced different body conditions for both sexes, whereas salinity only affected the condition of males. Such seasonal patterns might be explained by food availability. Body condition was highest during spring and, periods corresponding to high availability of zooplankton, the main prey item of these shrimps. Salinity had a different impact on males than females. The body condition of males was higher in more saline areas. This could be linked to a higher abundance of preys but also to a lower energy loss due to osmoregulation (González-Ortegón et al., 2006). On the other hand females tend to be located in oligohaline and fresh waters (Béguer et al., 2010a). The low range of salinity observed for sampled females may explain the absence of a statistical relationship with their body condition. Difference in location and body condition between males and females against physical factors can currently not be explained. However, the present study excluded the effect of turbidity or density-dependence on this parameter.

Further studies should seek to distinguish among the different diets of both sexes and to monitor prey availability as well as the effect of organic contamination. Furthermore, futures studies should take into account the variables mentioned above (salinity, season, sex) to allow for proper comparison of the growth and body condition between populations from different geographic areas.

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REFERENCES

- Anger, K., and G. S. Moreria. 1998. Morphometric and reproductive traits of tropical caridean shrimps. *Journal of Crustacean Biology* 18: 823-838.

- Aurousseau, J. 1984. Eléments d'écologie de la crevette blanche, *Palaemon longirostris*, dans l'estuaire de la Gironde. Dynamique de la population et production. Thèse de doctorat, Biologie Animale mention Ecologie. Université Paris VI, Paris, France. 227 pp.
- Béguier, M., J. Bergé, M. Girardin, and P. Boët. 2010a. Reproductive biology of *Palaemon longirostris* (Palaemonidae): Comparison of the Gironde estuary population with European ones. *Journal of Crustacean Biology* 30: 175-185.
- , L. Feuillassier, P. Elie, P. Boët, and M. Girardin. 2010b. Exoskeletal deformities in Palaemonidae: Are they a threat to survival? *Marine Environmental Research* 69: 109-117.
- , S. Pasquaud, C. Boët, P. Noël, and M. Girardin. 2008. First description of main skeletal deformations in shrimps populations of the Gironde estuary (France). *Hydrobiologia* 607: 225-229.
- Bergstrom, B. 1992. Growth, growth modelling and age determination of *Pandalus borealis*. *Marine Ecology Progress Series* 83: 167-183.
- Bilgin, S., O. Ozen, and O. Samsun. 2009. Sexual seasonal growth variation and reproduction biology of the rock pool prawn, *Palaemon elegans* (Decapoda: Palaemonidae) in the southern Black Sea. *Scientia Marina* 73.
- Blackwell, B. G., M. L. Brown and D. W. Willis. 2000. Relative weight *W_r* status and current use in fisheries assessment and management. *Reviews in Fisheries Science* 8: 1-44.
- Bourdon, T. 1965. Inventaire de la faune Marine de Roscoff. Décapodes – Stomatopodes. Editions de la Station Biologique de Roscoff, 45 pp.
- Brêthes, J. C., and R. N. O. Boyle. 1990. Méthodes d'évaluation des stocks halieutiques vol. 1 et 2. Project CIEO-860060, Centre International d'Exploration des Océans, Halifax.
- Campbell, P. J., and M. B. Jones. 1989. Osmoregulation of the estuarine prawn *Palaemon longirostris* (Caridea: Palaemonidae). *Journal of the Marine Biological Association of the United Kingdom* 69: 261-272.
- Campos, J., V. Freitas, C. Pedrosa, R. Guillot, and H. W. van der Veer. 2009. Latitudinal variation in growth of *Crangon crangon* (L.): Does counter-gradient growth compensation occur? *Journal of Sea Research* 62: 229-237.
- Cartaxana, A. 1994. Distribution and Migrations of the Prawn *Palaemon longirostris* in the Mira River Estuary (Southwest Portugal). *Estuaries* 17: 685-694.
- . 2003. Growth of the prawn *Palaemon longirostris* (Decapoda, Palaemonidae) in Mira river and Estuary, SW Portugal. *Journal of Crustacean Biology* 23: 251-257.
- Costanza, R., R. D'Arge, R. De Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253-260.
- d'Udekem d'Acoz, C. 1999. Inventaire et distribution des crustacés décapodes de l'Atlantique nord-oriental, de la Méditerranée et des eaux continentales adjacentes au nord de 25°N. Collection Patrimoines Naturels, 40. Muséum national d'Histoire Naturelle, Paris, France. 383 pp.
- De Man, J. G. 1923. *Leander longirostris* (H. Milne-Edwards) var. *robusta* nov. var., the common prawn of the estuary of the Meuse and of the Hollandsch Diep. *Tijdschrift der Nederlandsche Dierkundige Vereeniging* 19: 1-9.
- Deegan, L. A., J. T. Finn, S. G. Ayvazian, C. A. Ryder-Kieffer, and J. Buonaccorsi. 1997. Development and validation of an estuarine biotic integrity index. *Estuaries* 20: 601-617.
- Elkaim, B. 1974. Contributions à l'étude écologique d'un estuaire atlantique marocain: l'estuaire du Bou Regreg. Thèse d'Etat, Université de Bordeaux I: 251 pp.
- EU, 2000. Parliament and Council Directive 2000/60/EC of 23rd October 2000. Establishing a Framework for Community Action in the field of Water Policy. Official Journal PE-CONS 3639/1/00 REV 1.
- Garcia, S., and L. Le Reste. 1981. Cycles vitaux, dynamique, exploitation et aménagement des stocks de crevettes penaeides côtières. *FAO Doc. Tech. Pêches* (203): 1-210.
- Girardin, M., G. Castelnaud, A. Laplaud, and P. Gonthier. 2008. Surveillance halieutique de l'estuaire de la Gironde - suivi des captures 2006-2007 - étude de la faune circulant 2007. Rapport pour EDF CNPE du Blayais/ Etude Cemagref, étude n°124, groupement de Bordeaux Cestas, Bordeaux. 250 pp.
- González-Ortegón, E., and J. A. Cuesta. 2006. An illustrated key to species of *Palaemon* and *Palaemonetes* (Crustacea: Decapoda: Caridea) from European waters, including the alien species *Palaemon macrodactylus*. *Journal of the Marine Biological Association of the United Kingdom* 86: 93-102.
- , E. Pascual, J. A. Cuesta and P. Drake. 2006. Field distribution and osmoregulatory capacity of shrimps in a temperate European estuary (SW Spain). *Estuarine Coastal and Shelf Science* 67: 293-302.
- Gurney, R. 1923. Some notes on *Leander longirostris* M. Edwards, and others British prawns. *Proceedings of the Zoological Society of London* VII: 97-123.
- Halpern, B. S., S. Walbridge, K. A. Selkoe, C. V. Kappel, F. Micheli, C. D'Agrosa, J. F. Bruno, K. S. Casey, C. Ebert, H. E. Fox, R. Fujita, D. Heinemann, H. S. Lenihan, E. M. P. Madin, M. T. Perry, E. R. Selig, M. Spalding, R. Steneck, and R. Watson. 2008. A global map of human impact on marine ecosystems. *Science* 319: 948-952.
- Hartnoll, R. G. 1985. Growth, sexual maturity and reproductive output, pp. 101-128. In: A. A. Balkema (ed.), *Factors in Adult Growth*. Rotterdam, The Netherlands.
- Hoenig, J. M., and R. C. Hanumara. 1982. A statistical study of a seasonal growth model for fishes. *Tech. Reports of the Department Computer Science and Statistics, University of Rhode Island, Narragansett*. 1-126 pp.
- Linnaeus, C. 1758. *Systema Naturae per Regna Tria Naturae, Secundum Classes, Ordines, Genera, Species, cum Characteribus, Differentiis, Synonymis, Locis* (edit. 10). Vol. 1. Laurentii Salvii, Holmiae [Stockholm].
- Lobry, L., V. David, S. Pasquaud, M. Lepage, B. Sautour, and R. Rochard. 2008. Diversity and stability of an estuarine trophic network. *Marine Ecology Progress Series* 358: 13-25.
- Macdonald, P. D. M., and P. E. J. Green. 1998. User's Guide to Program MIX: An Interactive Program for Fitting Mixtures of Distributions. 62 pp.
- Marchand, J. 1981. Observations sur l'écologie de *Crangon crangon* (Linné) et *Palaemon longirostris* H. Milne Edwards (Crustacea, Decapoda, Natantia) dans l'estuaire interne de la Loire (France). *Vie et Milieu* 31: 83-92.
- Milne Edwards, H. 1837. Histoire naturelle des crustacés, comprenant l'anatomie, la physiologie et la classification de ces animaux. Librairie de Roret. II, Paris. 532 pp.
- Neves, A. M. 1970. Notas sobre alguns Palaemonidae da Fauna Portuguesa com indicação de duas espécies novas para Portugal. *Arq. Mus. Bocage* 2: 379-406.
- Omori, M., and Y. Chida. 1988. Reproductive ecology of a caridean shrimp *Palaemon macrodactylus* in captivity. *Nippon Suisan Gakkaishi* 54: 377-383.
- Pasquaud, S., P. Elie, C. Jeantet, I. Billy, P. Martinez, and M. Girardin. 2008. A preliminary investigation of the fish food web in the Gironde estuary, France, using dietary and stable isotope analyses. *Estuarine Coastal and Shelf Science* 78: 267-279.
- Pauly, D., and J. L. Munro. 1984. Once more on the comparison of growth in fish and invertebrates. *Fishbyte* 2: 21.
- , J. Moreau, and M. Soriano. 1992. A new model accounting for seasonal cessation of growth in fishes. *Australian Journal of Marine and Freshwater Research* 43: 1151-1156.
- R Foundation Core Team. 2005. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
- Sezgin, M., E. Eydemir, A. Suat Ateş, T. Katağan, and T. Özcan. 2007. On the presence of the non-native estuarine shrimp, *Palaemon longirostris* H. Milne-Edwards, 1837 (Decapoda, Caridea), in the Black Sea. *Aquatic Invasions* 2: 464-465.
- Smaldon, G., L. B. Holthuis, and C. H. J. M. Fransen. 1993. Coastal shrimps and prawns. Keys and notes for the identification of the species. *Synopses of the British Fauna (New Series)*. Oxford University Press, London. 142 pp.
- Taylor, C. C. 1962. Growth equation with metabolic parameters. *Journal du Conseil International pour l'Exploration de la Mer* 27: 270-286.
- van den Brink, F. W. B., and G. van der Velde. 1986. Observation on the population dynamics and distribution of the White Prawn *Palaemon longirostris* H. Milne Edwards, 1837 (Crustacea Decapoda Natantia) in the Netherlands, with special reference to its occurrence in the major rivers. *Archiv für Hydrobiologie* 107: 465-495.
- von Bertalanffy, L. 1938. A quantitative theory of organic growth (Inquiries on growth laws. II). *Human Biology* 10: 181-213.

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